# Integrated Management Tactics for *Frankliniella* Thrips (Thysanoptera: Thripidae) in Field-Grown Pepper

STUART R. REITZ,[1,2] ERIKA L. YEARBY,[1,3] JOSEPH E. FUNDERBURK,[4] JULIANNE STAVISKY,[4] M. TIMUR MOMOL,[4] AND STEVE M. OLSON[4]

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**ABSTRACT** In a 2-yr study, the impacts of different plastic soil mulches, insecticides, and predator releases on *Frankliniella* thrips and their natural enemies were investigated in field-grown peppers. Ultraviolet light (UV)-reflective mulch significantly reduced early season abundance of adult thrips compared with standard black plastic mulch. This difference diminished as the growing seasons progressed. Late season abundance of thrips larvae was higher in UV reflective mulch compared with black mulch plots. The abundance of the predator *Orius insidiosus* (Say) was significantly lower in UV-reflective mulch compared with black mulch treatments. Infection of plants with tomato spotted wilt virus, a pathogen vectored by *Frankliniella occidentalis* (Pergande), was <6%. In the year with the higher disease incidence (2000), UV-reflective mulch plots had significantly less disease (1.9%) compared with black mulch plots (4.4%). Yield was significantly higher in UV-reflective mulch (24,529 kg/ha) compared with black mulch (15,315 kg/ha) during this year. Effects of insecticides varied with species of thrips. Spinosad reduced abundance of *F. occidentalis,* but not *Frankliniella tritici.* In contrast, esfenvalerate and acephate reduced numbers of *F. tritici* and *Frankliniella bispinosa,* but resulted in higher populations of *F. occidentalis.* Spinosad was the least disruptive insecticide to populations of *O. insidiosus.* Releases of *O. insidiosus* and *Geocoris punctipes* (Say) reduced populations of thrips immediately after releases; naturally occurring predators probably provided late season control of thrips. Our results suggest that UV-reflective mulch, combined with early season applications of spinosad, can effectively reduce abundance of thrips in field-grown pepper.

**KEY WORDS** *Frankliniella, Orius insidiosus, Geocoris punctipes*, UV reflective mulch, spinosad

Thrips in the genus *Frankliniella* (Thysanoptera: Thripidae) are among the most important insect pests of vegetable crops in the southeastern United States. Several of these species occur in large numbers in vegetables grown in this region and are capable of causing esthetic damage to crops through their feeding and oviposition. However, some species, such as *Frankliniella occidentalis* (Pergande), pose additional risks as vectors of tomato spotted wilt virus (TSWV) (Ullman et al. 1997, Bauske 1998). Common *Frankliniella* species in the southeastern United States, including *F. occidentalis, Frankliniella tritici* (Fitch), *Frankliniella bispinosa* (Morgan), and *Frankliniella fusca* (Hinds), are morphologically similar yet display different population dynamics in agroecosystems (Eckel et al. 1996, Funderburk et al. 2000, Reitz et al. 2002), but not all (i.e., *F. tritici*) are vectors of TSWV. These factors complicate management strategies. Because of the exceedingly low tolerances for damage, management of thrips in vegetable crops has relied heavily on insecticides (Bauske 1998), which risks the development of insecticide resistance (Immaraju et al. 1992, Robb et al. 1995).

Alternative management tactics for thrips in open field vegetable crops have been explored. One promising cultural control is the use of plastic soil mulches that reflect ultraviolet (UV) light. Growing vegetables on plastic mulches is a standard cultural practice in the southeastern United States and elsewhere in the world (Krug 1991, Castro et al. 1993, Vos et al. 1995, Hochmuth 1997), because these materials provide several benefits, including improved retention of irrigation water and soil moisture, conservation of soil applied fertilizers, modulation of soil temperatures, and weed suppression. Because thrips locate suitable host plants in part through visual cues in the UV spectrum (Walker 1974, Terry 1997), materials that reflect UV radiation could obscure host location cues used by thrips. Hence, the addition of UV-reflective components to mulches may help delay or reduce immigration of thrips into crops and consequent incidence of tomato spotted wilt, as has been shown for tomatoes, *Lycopersicon esculentum* (Mill.) (Stavisky et al. 2002). How-

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[1] USDA–ARS, Center for Biological Control, 310 Perry-Paige Building, Florida A&M University, Tallahassee, FL 32307.

[2] E-mail: sreitz@nettally.com.

[3] Center for Biological Control, Florida A&M University, Tallahassee, FL 32307.

[4] University of Florida, North Florida Research and Education Center, 155 Research Road, Quincy, FL 32351.

ever, such reductions in the abundance of thrips without reduction in the incidence of tomato spotted wilt have occurred in other studies with UV-reflective mulches in tomatoes (Greenough et al. 1990, Riley and Pappu 2000).

Research on the influence of UV-reflective mulches on thrips and tomato spotted wilt in pepper (*Capsicum anuum* L.) has produced inconclusive results. Some trials have shown that UV-reflective mulches lower numbers of thrips in pepper but have not led to decreased disease incidence or increased yield compared with conventional plastic mulches (Greenough et al. 1990, Kring and Schuster 1992, Vos et al. 1995). Pepper is a suitable reproductive host for *Frankliniella* species, thus making primary and secondary disease cycles of thrips-vectored pathogens possible (see Puche et al. 1995). Conversely, pepper also is a suitable host for many important natural enemies, such as *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) and *Geocoris punctipes* (Say) (Heteroptera: Lygaeidae), that are capable of suppressing thrips populations (Schoenig and Wilson 1992, Funderburk et al. 2000, Ramachandran et al. 2001). However, if UV reflective mulch interferes with the ability of natural enemies to locate prey, its use could disrupt these valuable natural control mechanisms (see Parker 1969, Freund and Olmstead 2000, for role of vision in predatory Heteroptera).

The objectives of this study were to compare the impact of UV-reflective mulch with that of standard black plastic mulch on key thrips species and natural enemies in a pepper agroecosystem. As an extension, we examined the effects of different insect management tactics (i.e., insecticides and predator releases) on thrips and their natural enemies and how the different mulches mediate these effects. Insecticides used in this study were selected for their common use in pepper production and differential impacts on species of thrips and natural enemies, which allows for various levels of inclusion or exclusion of pest and beneficial species. Information on how different types of management tactics can be integrated is important not only in regard to practical management considerations, but also to better understand the dynamics of thrips, their natural enemies, and thrips-vectored pathogens in open field cropping systems.

## Materials and Methods

**Cultural Practices.** Experiments were conducted at the University of Florida, North Florida Research and Education Center, Gadsden County, FL, during the spring of 2000 and 2001. Six-wk-old pepper plants ('Camelot') were transplanted into raised beds on 22 March 2000 and 20 March 2001. Beds consisted of two linear rows of pepper plants and were 15 cm high and 91 cm wide. Beds were covered with plastic mulch, and a drip tube underneath the plastic provided irrigation. Plant spacing was 30 cm within and between rows, with a bed spacing of 180 cm. Other cultural practices followed standards for northern Florida.

**Experimental Design and Methods.** The experimental design used in 2000 was a randomized complete block. There were four blocks with six treatment plots per block. Treatments were a combination of mulch type and insecticide treatment. Experimental plots were one bed wide and 13.7 m long, and there was a 1.5-m buffer between plots within each bed. The types of mulches used were a standard black plastic mulch (Huntsman Packaging, Tampa, FL) and a metalized UV-reflective silver mulch (Reflectek Foils, Lake Zurich, IL). The six treatments in 2000 were: (1) black mulch with no insecticide treatment; (2) spinosad (Spintor 2 SC, Dow Agrosciences, Indianapolis, IN, at 0.105 kg [AI]/ha) on black mulch; (3) acephate (Orthene 75SP, Valent, Walnut Creek, CA at 0.85 kg [AI]/ha) on black mulch; (4) esfenvalerate (Asana 0.66 SC, DuPont, Wilmington, DE, at 0.057 kg [AI]/ha) on black mulch; (5) UV-reflective mulch with no insecticide treatment; and (6) spinosad (at 0.075 kg [AI]/ha) on UV-reflective mulch. Chemicals were mixed with water (180 liters/ha) and applied using a gas pressurized backpack sprayer fitted with three hollow-cone nozzles (D7–45): one was directed straight into the plants on each side of the 2-row bed and a third nozzle was directed over the top of each bed. Applications of insecticides were initiated at the onset of flowering. Application dates were 1, 8, 15, and 22 May 2000.

In 2001, a randomized complete block split plot design was used. There were four blocks with the two different mulches (black and UV reflective) applied to whole plots within blocks. Whole plots were subdivided into six subplots, and each subplot was randomly assigned an insect management treatment. Subplots were one bed wide and 13.7 m long, and there was a 1.5-m buffer between subplots within each bed. Subplot treatments included (1) a nontreated control, (2) spinosad (at 0.105 kg [AI]/ha); (3) esfenvalerate (Asana 0.66 SC, at 0.057 kg [AI]/ha); (4) indoxacarb (Avaunt 3G, DuPont, Wilmington, DE, at 0.073 kg [AI]/ha); (5) release of *O. insidiosus* adults (Entomos, Gainesville, FL, at ≈144,000/ha); and (6) release of *G. punctipes* nymphs (Entomos at ≈144,000/ha). Insecticides were applied as in 2000, except that the sprayer was fitted with four hollow-cone nozzles (D7–45), one was directed straight into the plants on each side of the two-row bed and a nozzle was directed over the top of each row of plants. Applications of insecticides were made on 1, 8, and 15 May 2001. Predators were released on 3 May 2001 by sprinkling equal amounts of predators, packed in vermiculite, onto plants.

**Data Collection and Analysis.** In field-grown pepper, *Frankliniella* spp. and *O. insidiosus* are found almost exclusively in flowers (Hansen 2000), therefore insect samples were collected twice per wk by removing one flower from each of 10 plants from in the middle of one row per plot. Flowers were placed in 70% ethanol for later examination. Sampling was conducted from the onset to conclusion of flowering. In 2000, sampling began after the first insecticide application. In 2001, samples were collected on two dates before the first insecticide application. All samples

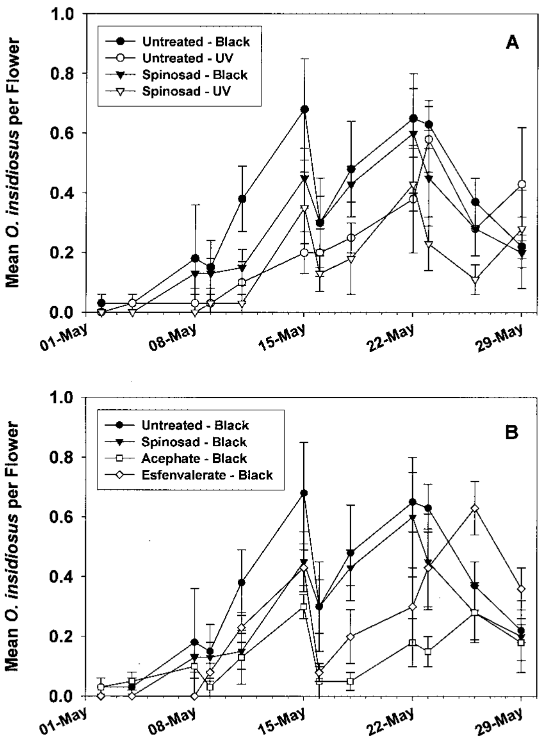


**Fig. 1.** Number (mean ± SEM) of *O. insidiosus* in flowers of pepper plants grown under different mulch and insecticide treatments during the spring of 2000. Figure 1A compares corresponding black and UV-reflective mulch treatments. Figure 1B compares insecticide treatments made on black mulch. Insecticide applications were made on 1, 8, 15, and 22 May. Samples collected on those dates were collected before insecticide applications. Means and their standard errors are based on untransformed data.

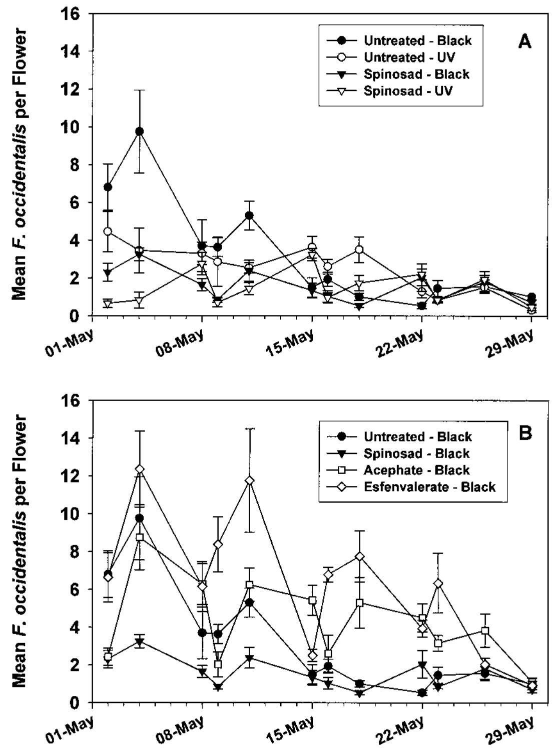


**Fig. 2.** Number (mean ± SEM) of adult thrips of *F. occidentalis* in flowers of pepper plants grown under different mulch and insecticide treatments during the spring of 2000. Figure 2A compares corresponding black and UV-reflective mulch treatments. Figure 2B compares insecticide treatments made on black mulch. Insecticide applications were made on 1, 8, 15, and 22 May. Samples collected on those dates were collected before insecticide applications. Means and their standard errors are based on untransformed data.

were collected between 1000 and 1200 hours Eastern Standard Time. During the time insecticides were applied, samples were taken the morning before insecticide sprays, and then one to three d after spraying. In the laboratory, thrips were extracted from flowers, and adults were sexed and identified to species, using a 40× stereomicroscope. Because it was not possible to identify thrips larvae to species, they were combined into a single group for analysis. The total number of flowers collected per plot was recorded.

The incidence of tomato spotted wilt was assessed each wk, from transplanting until harvest, by visually inspecting plants for symptoms of the disease. Diagnostic tests for tomato spotted wilt virus (Agdia, Elkhart, IN) were performed on plants with apparent symptoms. Plants that tested positive for tomato spotted wilt virus were marked so disease progression could be monitored over the course of the season.

Yield was assessed by harvesting all marketable fruit from 20 healthy plants in the row opposite of where sampling of flowers took place in each plot. Fruit were harvested once per season, on 26 June 2000, and on 21 June 2001. Fruit were graded for quality according to

**Table 1. Analysis of variance statistics for the effect of mulch type and the date × mulch interaction on abundance of *Frankliniella* thrips and the predator *O. insidiosus***

| Season | Variable | df | *O. insidiosus* | | *F. occidentalis* | | *F. tritici* | | *F. bispinosa* | | Thrips Larvae | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *F* | *P* | *F* | *P* | *F* | *P* | *F* | *P* | *F* | *P* |
| 2000 | Mulch[a] | 1, 14 | 15.15 | 0.009 | 6.13 | 0.027 | 147.90 | 0.0001 | 21.61 | 0.0004 | 4.15 | 0.061 |
| | Date × mulch[a] | 11, 154 | 1.87 | 0.12 | 8.30 | 0.0001 | 11.01 | 0.0001 | 5.29 | 0.0001 | 3.45 | 0.015 |
| 2001 | Mulch | 1, 3 | 29.95 | 0.012 | 1.75 | 0.28 | 52.55 | 0.005 | 36.22 | 0.009 | 162.73 | <0.0001 |
| | Date × mulch | 9, 27 | 3.62 | 0.0045 | 26.77 | <0.0001 | 29.90 | 0.0001 | 6.66 | <0.0001 | 22.63 | <0.0001 |

[a] Mulch comparisons for 2000 are for untreated and spinosad-treated black mulch treatments versus untreated and spinosad-treated UV reflective mulch treatment.

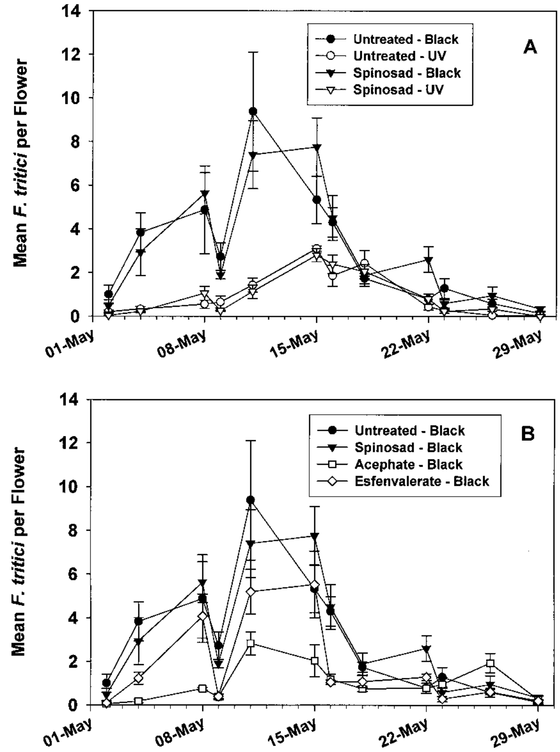


**Fig. 3.** Number (mean ± SEM) of adult thrips of *F. tritici* in flowers of pepper plants grown under different mulch and insecticide treatments during the spring of 2000. Figure 3A compares corresponding black and UV-reflective mulch treatments. Figure 3B compares insecticide treatments made on black mulch. Insecticide applications were made on 1, 8, 15, and 22 May. Samples collected on those dates were collected before insecticide applications. Means and their standard errors are based on untransformed data.

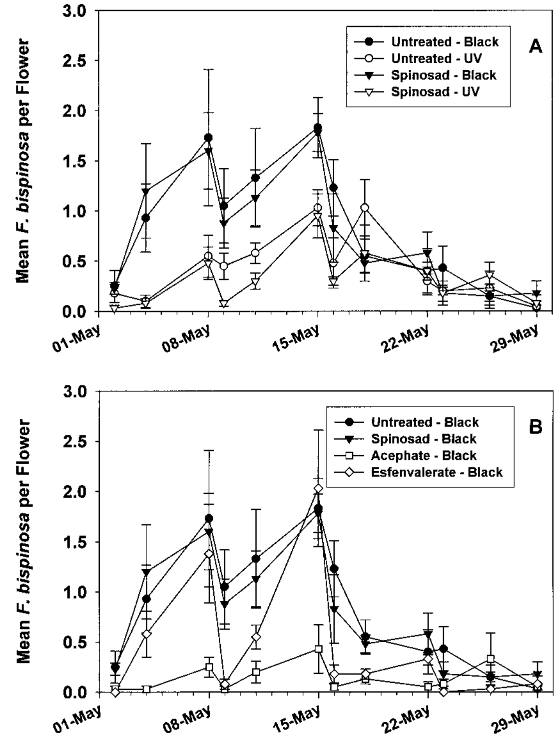


**Fig. 4.** Number (mean ± SEM) of adult thrips of *F. bispinosa* in flowers of pepper plants grown under different mulch and insecticide treatments during the spring of 2000. Figure 4A compares corresponding black and UV-reflective mulch treatments. Figure 4B compares insecticide treatments made on black mulch. Insecticide applications were made on 1, 8, 15, and 22 May. Samples collected on those dates were collected before insecticide applications. Means and their standard errors are based on untransformed data.

USDA standards and weighed. Only marketable fruit were included in analyses.

All data were checked for normality and homoscedacity. Total numbers of thrips and natural enemies per sample were divided by the number of flowers per sample before statistical analysis. Insect and yield data were transformed logarithmically to reduce correlations between means and variances. Tomato spotted wilt incidence data were transformed to arcsine of their square root before analysis. Data were analyzed separately for each season. Insect data were analyzed as repeated measures analysis of variance (ANOVA) over time (Steel and Torrie 1980, Littell et al. 1991). Disease progress curves were generated based on incidence of plants testing positive for tomato spotted wilt. The cumulative percentage of infected plants at the end of each season were analyzed by ANOVA. Yield data also were analyzed by ANOVA for each season. Linear contrasts were used to make specific comparisons among treatment groups over each season (SAS Institute 1989). We assessed the impact of insecticides and predator releases by comparing differences among treatment groups on the sample date following applications (ESTIMATE statement of PROC GLM, SAS Institute 1989, Littell et al. 1991). Untransformed means and standard errors are presented.

For the 2000 season, we compared the UV-reflective mulch treatments (untreated and spinosad-treated) to their corresponding black mulch treatments to determine whether UV-reflective mulch reduced insect populations and the incidence of tomato spotted wilt while increasing yield. In addition, we compared spinosad, a reduced risk insecticide (EPA 1996, 2002) with toxicity against thrips (Eger et al. 1998), with acephate, a broad-spectrum organophosphate, and esfenvalerate, a broad-spectrum pyrethroid, and how these compared individually with the untreated black mulch control.

For the 2001 season, we compared the two types of mulches. Furthermore, we individually compared spinosad, indoxacarb (also a reduced-risk insecticide), esfenvalerate, and the predator releases with the untreated control. We also compared spinosad with the predator releases and with esfenvalerate. For the 2001 season, we analyzed insect data from sample dates

**Table 2. Comparison of insecticide treatments on sample dates following insecticide applications (made on 1, 8, 15, and 22 May) for the 2000 season**

| Taxon | Comparison[a] ($\mu_i - \mu_j$) | 2 May 2000 difference ($x \pm$ SEM)[b] | 9 May 2000 difference ($x \pm$ SEM) | 16 May 2000 difference ($x \pm$ SEM) | 23 May 2000 difference ($x \pm$ SEM) | Season $F_{1, 14}$ | Season $P$ |
|---|---|---|---|---|---|---|---|
| *O. insidiosus* | Untreated—Spinosad | 0.0 ± 0.0 | −0.1 ± 0.1 | 0.1 ± 0.1 | 0.2 ± 0.2 | 2.06 | 0.17 |
| | Untreated—Acephate | −0.1 ± 0.1 | 0.0 ± 0.1 | 0.3 ± 0.1 | 0.5 ± 0.2*[c] | 19.70 | 0.006 |
| | Untreated—Esfenvalerate | 0.0 ± 0.0 | 0.0 ± 0.1 | 0.2 ± 0.1 | 0.2 ± 0.2 | 4.70 | 0.05 |
| | Spinosad—Acephate + Esfenvalerate | −0.1 ± 0.1 | 0.1 ± 0.0* | 0.3 ± 0.1* | 0.2 ± 0.1 | 5.59 | 0.03 |
| *F. occidentalis* | Untreated—Spinosad | 5.9 ± 1.2* | 2.8 ± 1.3* | 0.8 ± 0.8 | 1.0 ± 1.2 | 58.61 | <0.0001 |
| | Untreated—Acephate | 5.8 ± 1.2* | 1.6 ± 1.3 | −0.7 ± 0.8 | −1.4 ± 1.2 | 24.96 | 0.0002 |
| | Untreated—Esfenvalerate | 1.6 ± 1.2 | −4.7 ± 1.3* | −4.9 ± 0.8* | −4.5 ± 1.2* | 99.46 | <0.0001 |
| | Spinosad—Acephate + Esfenvalerate | −2.2 ± 0.9* | −4.4 ± 1.0* | −3.7 ± 0.7* | −3.9 ± 0.9* | 366.79 | <0.0001 |
| *F. tritici* | Untreated—Spinosad | 0.6 ± 0.3 | 0.5 ± 0.4 | 0.1 ± 1.0 | 0.9 ± 0.3* | 0.05 | 0.83 |
| | Untreated—Acephate | 1.0 ± 0.3* | 2.0 ± 0.3* | 3.4 ± 1.0* | 0.5 ± 0.3 | 54.19 | 0.0001 |
| | Untreated—Esfenvalerate | 1.0 ± 0.3* | 2.0 ± 0.3* | 3.5 ± 1.0* | 1.2 ± 0.2* | 22.79 | 0.003 |
| | Spinosad—Acephate + Esfenvalerate | 0.4 ± 0.2* | 1.5 ± 0.3* | 3.4 ± 0.8* | −0.1 ± 0.3 | 63.48 | 0.0001 |
| *F. bispinosa* | Untreated—Spinosad | 0.0 ± 0.1 | 0.3 ± 0.2 | 0.3 ± 0.3 | 0.4 ± 0.1* | 0.08 | 0.78 |
| | Untreated—Acephate | 0.3 ± 0.1* | 1.2 ± 0.2* | 1.1 ± 0.3* | 0.5 ± 0.1* | 32.41 | 0.0001 |
| | Untreated—Esfenvalerate | 0.3 ± 0.1* | 1.1 ± 0.2* | 1.0 ± 0.3* | 0.6 ± 0.1* | 10.42 | 0.006 |
| | Spinosad—Acephate + Esfenvalerate | 0.2 ± 0.1* | 0.8 ± 0.2* | 0.7 ± 0.2* | 0.1 ± 0.1 | 27.84 | 0.0001 |
| Thrips Larvae | Untreated—Spinosad | 9.3 ± 2.9* | 11.8 ± 1.9* | 2.6 ± 0.9 | 0.7 ± 1.5 | 54.40 | 0.0001 |
| | Untreated—Acephate | 7.1 ± 2.9 | 6.3 ± 1.9* | −1.6 ± 0.9 | −3.8 ± 1.5* | 16.13 | 0.001 |
| | Untreated—Esfenvalerate | 5.4 ± 2.9 | −0.5 ± 1.9 | −8.6 ± 0.9* | −4.6 ± 1.5* | 15.86 | 0.001 |
| | Spinosad—Acephate + Esfenvalerate | −3.1 ± 2.3 | −9.0 ± 1.5* | −7.6 ± 2.3* | −4.9 ± 1.1* | 207.02 | 0.0001 |

[a] Comparisons involve treatments with black mulch only. Comparisons for sample dates following applications are based on univariate ANOVAs. Seasonal comparisons are based on repeated-measures ANOVAs.
[b] Untransformed values are given.
[c] Mean differences marked with an asterisk (*) are significantly different from 0, $P < 0.05$. Analyses are based on log-transformed values.

before the first insecticide application separately from the sample dates after applications began.

## Results

In both seasons, the most abundant species of adult thrips in pepper flowers were *F. occidentalis* and *F. tritici*, although the proportions of these species changed from one season to the next. In 2000, *F. occidentalis* comprised 58.6% of the adults collected but only 33.6% in 2001. In contrast, *F. tritici* comprised only 32.6% of the adults collected in 2000, but 60.2% in 2001. Relatively few *F. bispinosa* (8.8 and 6.2% of adult thrips for 2000 and 2001, respectively) or *F. fusca* (<0.1% of adult thrips in both years) were collected.

**2000 Season.** *Orius insidiosus* colonized all treatments to some extent. Number of *O. insidiosus* increased over the course of the season, but there was no significant date by treatment interaction ($F = 1.87$; df = 55, 154; $P = 0.11$; Fig. 1), indicating that responses to the various treatments remained consistent over time. There was a significant difference among treatments in the number of *O. insidiosus* over the entire season ($F = 5.77$; df = 5, 14; $P = 0.004$). This result stemmed largely from differences between the types of mulch, with significantly higher numbers of *O. insidiosus* occurring in black mulch compared with UV-reflective mulch treatments (Table 1; Fig. 1).

Early season abundance of adult thrips was significantly lower in UV reflective mulch compared with black mulch treatments. The significant date by mulch interactions indicate that these differences did not persist throughout the season (Table 1; Figs. 2-4).

Insecticides had a significant impact on populations of adult thrips; however, the species responded differently to the various insecticides. Large differences occurred among insecticide treatments for *F. occidentalis*, with extremely high populations found in the esfenvalerate and acephate treatments and comparatively low populations found with spinosad (Table 2; Fig. 2). *Frankliniella occidentalis* populations tended to increase subsequent to applications of acephate and esfenvalerate, but decreased within the following 6 d.

The insecticides had significant effects on the populations of *F. tritici* and *F. bispinosa*, but these impacts were opposite from those on *F. occidentalis* (Figs. 3 and 4). Populations of *F. tritici* and *F. bispinosa* collapsed soon after 16 May, which coincided with the rapid increase in *O. insidiosus* populations (Fig. 1). Acephate and esfenvalerate were highly toxic to *F. tritici*, as indicated by the low populations immediately following applications (Table 2; Fig. 3). Similar to the results obtained for *F. tritici*, spinosad did not appear to have an adverse effect on populations of *F. bispinosa*. Significantly lower populations of *F. bispinosa* occurred in the acephate and esfenvalerate treatments following certain applications (Table 2; Fig. 4). For the entire 2000 season, acephate and esfenvalerate reduced *F. bispinosa* numbers compared with the untreated black mulch control (Table 2; Fig. 4). In contrast to the results obtained for *F. occidentalis*, spinosad did not significantly reduce populations of *F. bispinosa* compared with the control.

The number of thrips larvae also varied significantly among treatments ($F = 66.01$; df = 5, 14; $P < 0.0001$). Populations in the untreated plots peaked early in the season and then declined to near extinction by the end of the season (Fig. 5). There was a significant interaction between mulches and dates in number of larvae (Table 1; Fig. 5). As the season progressed the pro-

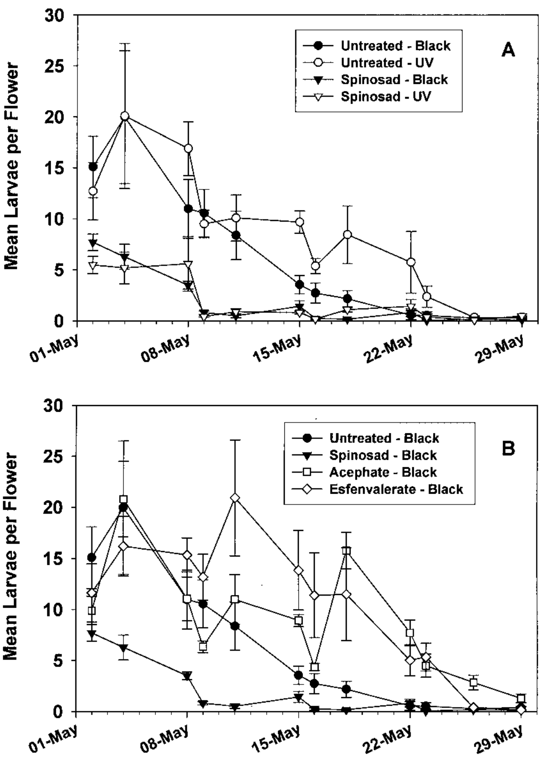


**Fig. 5.** Number (mean ± SEM) of larval thrips in flowers of pepper plants grown under different mulch and insecticide treatments during the spring of 2000. Figure 5A compares corresponding black and UV-reflective mulch treatments. Figure 5B compares insecticide treatments made on black mulch. Insecticide applications were made on 1, 8, 15, and 22 May. Samples collected on those dates were collected before insecticide applications. Means and their standard errors are based on untransformed data.

portion of larvae found increased in the UV reflective mulch compared with black mulch. This result suggests that, although the UV reflective mulch inhibited adult thrips from landing on plants, it did not deter oviposition. Spinosad was the most effective treatment in reducing larval thrips numbers over the course of the season (Table 2; Fig. 5). Overall numbers of larvae were significantly higher in the acephate and esfenvalerate plots compared with the untreated black mulch plots, although these differences did not occur on all sample dates.

The incidence of tomato spotted wilt was relatively low throughout the 2000 season. Diseased plants were found on each of the sample days, but the biggest increase in disease incidence was detected late in the season on 8 June 2000. The cumulative disease incidence in the UV-reflective mulch treatments was significantly lower than the disease incidence in the corresponding black mulch treatments ($F = 7.07$; df = 1, 14; $P = 0.017$). The mean percentage diseased plants ranged from 1.9 ± 0.6% in the two UV-reflective mulch treatments to 5.2% ± 0.6% in the black mulch treatment with spinosad, and 5.2% ± 0.8% with acephate. None of the other comparisons resulted in significant differences.

The marketable yield from the UV-reflective mulch (24,529 ± 1,922 kg/ha) was significantly greater than the yield from the black mulch (15,315 ± 2,153 kg/ha; $F = 7.40$; df = 1, 14; $P = 0.016$). In addition to the greater total weight of fruit harvested from the UV-reflective mulch treatments, the average size of fruits harvested from those treatments (199.6 ± 5.8 g) was significantly greater than that from the black mulch (176.7 ± 4.6 g; $F = 15.41$; df = 1, 14; $P = 0.0013$).

**2001 Season.** There were no significant differences between the mulches on the two sample days before insecticide applications and predator releases began ($P > 0.20$ for thrips and *O. insidiosus*). Not all plants were flowering before 1 May 2001. Therefore, the lack of significant differences between mulches at this early stage may reflect variable colonization of a limited, newly available resource by relatively low numbers of thrips. The low number of larval thrips on these pretreatment sample days indicates that the pepper plants had only been recently colonized. With few thrips available, there were virtually no *O. insidiosus* present on these early sample dates (Fig. 6). Sampling flowers for *G. punctipes* lacked precision and accuracy (unpublished data); therefore, no results for that species are given. However, data on abundance of thrips and *O. insidiosus* in *G. punctipes* release treatments are included, as well as disease incidence and yield data.

Once *O. insidiosus* numbers started to increase after 1 May 2001, there were significant differences in its abundance between the mulches, with greater numbers in the black mulch treatments compared with the UV-reflective mulch treatments (Table 1; Fig. 6). However, there was also an interaction among insecticide/predator release treatment and mulch and date ($F = 1.94$; df = 45, 261; $P = 0.005$). The interaction appears to have been caused by high numbers collected in UV-reflective mulch treatments in which *O. insidiosus* were released compared with black mulch treatments in which *O. insidiosus* were released. On the day after the release (4 May 2001), all *O. insidiosus* collected were adults, and there were over twice as many in UV-reflective mulch plots in which releases were made as in corresponding black mulch plots (Fig. 6). This result suggests that the released *O. insidiosus* may have been arrested by UV reflectance. In other UV-reflective mulch treatments, *O. insidiosus* numbers were substantially lower compared with the corresponding black mulch treatments, suggesting a repellent effect of UV-reflective mulch. On 11 and 15 May 2001, the high number of *O. insidiosus* in the UV-reflective mulch consisted almost entirely of young nymphs (92% and 97%, respectively), suggesting that adults, which arrested upon release, had oviposited before eventually dispersing. Beyond obvious differences between release and nonrelease treatments (Table 3; Fig. 6), there were significantly fewer *O. insidiosus* in the esfenvalerate treatments compared with the untreated controls over the season, although this difference was not apparent on postapplication sample dates. No *O. insidiosus* were found in

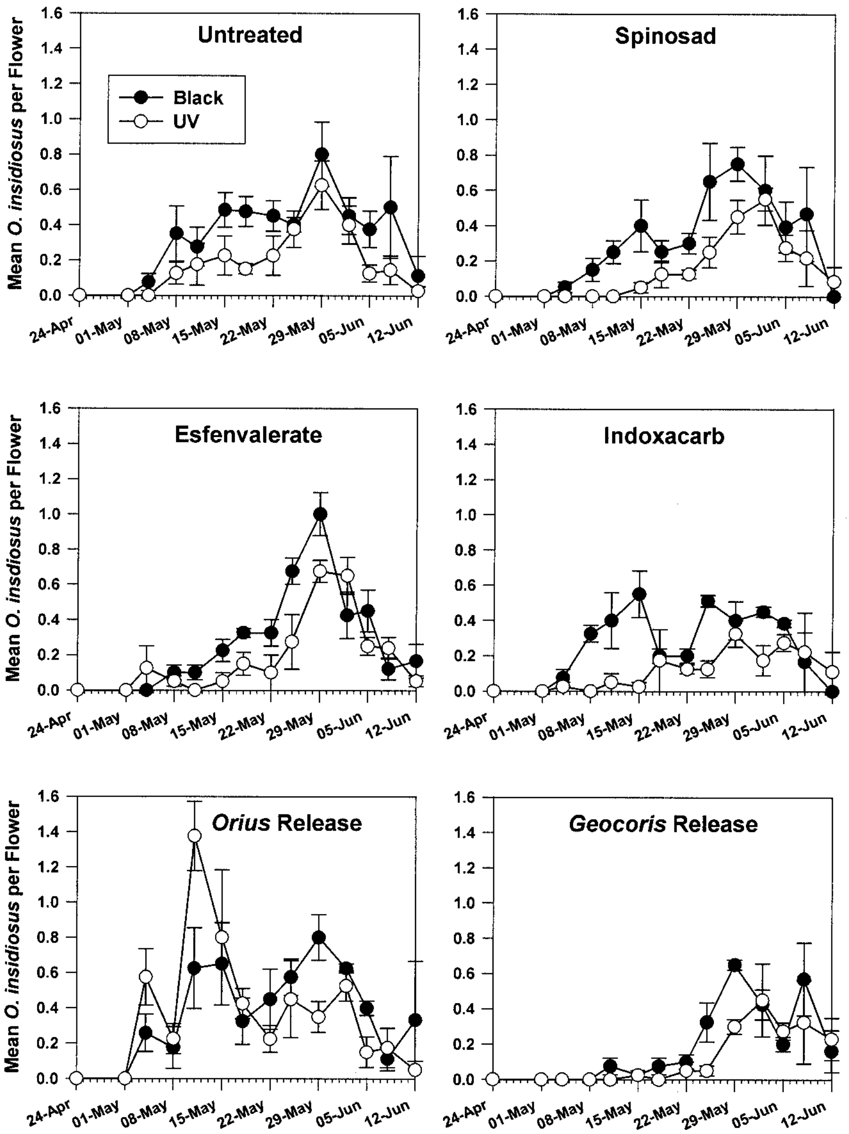


**Fig. 6.** Number (mean ± SEM) of *O. insidiosus* in flowers of pepper plants grown under different insect management and mulch treatments during the spring of 2001. Insecticide applications were made on 1, 8, and 15 May. Samples collected on those dates were collected before insecticide applications. Predators were released on 3 May. Means and their standard errors are based on untransformed data.

the *G. punctipes* release treatments during the week following predator releases, and *O. insidiosus* numbers remained low in those plots (<0.30 per flower) until 29 May (Fig. 6).

Thrips species had variable responses to the different mulches, but there were no significant insecticide/predator release treatment by mulch interactions evident, thus indicating no synergistic or antagonistic effects between any of these treatment factors. Populations of adult and larval thrips were nearly extinct by 29 May 2001 (Figs. 7-10), which coincided with the peak abundance of *O. insidiosus.* For *F. occidentalis,* there was a significant date by mulch interaction (Table 1). Early in the season, more *F. occidentalis* were present in the black mulch, but higher numbers persisted later in the season in the UV-reflective mulch (Fig. 7). This interaction led to there being no overall significant difference in numbers of *F. occidentalis* between the mulches in 2001. In contrast, *F. tritici* did not show a date by mulch interaction, but overall there were significantly more *F. tritici* in the black mulch treatments than in the UV-reflective mulch treatments (Table 1; Fig. 8). For *F. bispinosa,* as with *F. occidentalis,* there was a significant date by mulch interaction (Table 1; Fig. 9). Higher populations occurred in the black mulch treatments early in the season, whereas

**Table 3. Comparison of treatments on sample dates following insecticide applications (made on 1, 8, 15 May) and predator releases (made on 3 May) for the 2001 season**

| Taxon | Comparison[a] | Sample date | | | Season | |
|---|---|---|---|---|---|---|
| | | 4 May 2001 difference ($x \pm$ SEM)[b] | 11 May 2001 difference ($x \pm$ SEM) | 18 May 2001 difference ($x \pm$ SEM) | $F_{1, 29}$ | $P$ |
| *O. insidiosus* | Untreated—Spinosad | 0.0 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 1.14 | 0.29 |
| | Untreated—Avaunt | 0.0 ± 0.1 | 0.0 ± 0.1 | 0.1 ± 0.1 | 3.12 | 0.09 |
| | Untreated—Esfenvalerate | 0.0 ± 0.1 | 0.2 ± 0.1*[c] | 0.1 ± 0.1 | 0.67 | 0.42 |
| | Untreated—Predators[d] | −0.4 ± 0.1* | −0.8 ± 0.1* | −0.1 ± 0.1 | 8.98 | 0.006 |
| | Spinosad—Esfenvalerate | 0.0 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.06 | 0.80 |
| | Spinosad—Predators[d] | −0.4 ± 0.1* | −0.9 ± 0.1* | −0.2 ± 0.1 | 16.52 | 0.0003 |
| *F. occidentalis* | Untreated—Spinosad | 2.1 ± 0.5* | 2.0 ± 0.7* | 0.9 ± 0.3* | 24.72 | <0.0001 |
| | Untreated—Avaunt | 0.2 ± 0.5 | 0.5 ± 0.7 | −0.5 ± 0.3 | 0.39 | 0.54 |
| | Untreated—Esfenvalerate | −1.6 ± 0.5* | −4.1 ± 0.7* | −2.6 ± 0.3* | 47.69 | <0.0001 |
| | Untreated—Predators | 1.9 ± 0.5* | 1.5 ± 0.6* | 0.2 ± 0.3 | 15.22 | 0.0001 |
| | Spinosad—Esfenvalerate | −3.7 ± 0.5* | −6.1 ± 0.7* | −3.5 ± 0.3* | 141.08 | <0.0001 |
| | Spinosad—Predators | −0.2 ± 0.4 | −0.5 ± 0.6 | −0.7 ± 0.3* | 3.05 | 0.09 |
| *F. tritici* | Untreated—Spinosad | 1.1 ± 0.7 | 1.1 ± 1.2 | 0.3 ± 1.2 | 0.04 | 0.84 |
| | Untreated—Avaunt | 0.7 ± 0.7 | −0.3 ± 1.2 | −3.2 ± 1.2* | 3.96 | 0.06 |
| | Untreated—Esfenvalerate | 3.0 ± 0.6* | 6.4 ± 1.2* | 2.3 ± 1.2* | 26.97 | <0.0001 |
| | Untreated—Predators | 2.2 ± 0.6* | 3.3 ± 1.0* | −0.4 ± 1.1 | 4.15 | 0.05 |
| | Spinosad—Esfenvalerate | 1.9 ± 0.6* | 5.3 ± 1.2* | 2.0 ± 1.2* | 24.86 | <0.0001 |
| | Spinosad—Predators | 1.1 ± 0.6 | 2.2 ± 1.0 | −0.7 ± 1.1 | 3.24 | 0.08 |
| *F. bispinosa* | Untreated—Spinosad | 0.3 ± 0.2 | 0.6 ± 0.2* | 0.1 ± 0.1 | 6.32 | 0.02 |
| | Untreated—Avaunt | −0.1 ± 0.2 | −0.2 ± 0.2 | −0.3 ± 0.1* | 3.26 | 0.08 |
| | Untreated—Esfenvalerate | 0.7 ± 0.2* | 1.2 ± 0.2* | 0.1 ± 0.1 | 56.46 | <0.0001 |
| | Untreated—Predators | 0.5 ± 0.2* | 0.8 ± 0.2* | 0.1 ± 0.1 | 26.05 | <0.0001 |
| | Spinosad—Esfenvalerate | 0.5 ± 0.2* | 0.5 ± 0.2* | 0.1 ± 0.1 | 23.02 | <0.0001 |
| | Spinosad—Predators | 0.2 ± 0.2 | 0.2 ± 0.2 | 0.0 ± 0.1 | 5.06 | 0.03 |
| Thrips Larvae | Untreated—Spinosad | 5.9 ± 1.3* | 4.0 ± 0.9* | 1.1 ± 0.3* | 67.23 | <0.0001 |
| | Untreated—Avaunt | 0.9 ± 1.3 | −1.3 ± 0.9 | −0.4 ± 0.3 | 5.38 | 0.028 |
| | Untreated—Esfenvalerate | −0.2 ± 1.3 | −8.4 ± 0.9* | −4.5 ± 0.3* | 50.04 | 0.0001 |
| | Untreaetd—Predators | 4.1 ± 1.1* | 3.1 ± 0.8* | 0.6 ± 0.2* | 7.88 | 0.009 |
| | Spinosad—Esfenvalerate | −6.1 ± 1.3* | −12.3 ± 0.08* | −5.6 ± 0.3* | 233.28 | 0.0001 |
| | Spinosad—Predators | −1.9 ± 1.2* | −0.9 ± 0.8* | −0.5 ± 0.2* | 42.33 | 0.0001 |

[a] Comparisons for sample dates following applications are based on univariate ANOVAs. Seasonal comparisons are based on repeated-measures ANOVAs.
[b] Untransformed values are given.
[c] Mean differences marked with an asterisk (*) are significantly different from 0, $P < 0.05$. Analyses are based on log-transformed values.
[d] These comparisons are only for *O. insidiosus* releases and do not include the *G. punctipes* releases.

higher populations occurred in the UV-reflective mulch treatments later in the season. There was also a significant date by mulch interaction for larval thrips (Table 1), again indicating that higher populations occurred in the black mulch treatments early, whereas later in the season higher populations occurred in the UV-reflective mulch treatments (Fig. 10). However, for the season, significantly more larvae occurred in the UV-reflective mulch (Table 1).

Thrips also showed variable responses to insecticides and predator releases. Spinosad was the most effective insecticide against *F. occidentalis* and gave better control of *F. occidentalis* than did predator releases (Table 3; Fig. 7). In contrast, esfenvalerate was the least effective material against *F. occidentalis.* As in 2000, populations of this species tended to increase after applications of esfenvalerate, and decrease just before applications, possibly as natural enemies recolonized these plots. Indoxacarb did not appear to have an effect on *F. occidentalis* (Table 3; Fig. 7). Numbers of *F. occidentalis* were lower in the predator release treatments compared with the untreated controls for the first few sample days after releases.

The insecticides and predator releases had different effects on populations of *F. tritici* compared with *F. occidentalis* (Table 3; Fig. 8). Esfenvalerate significantly reduced numbers of *F. tritici* compared with the untreated controls, but only for the sample dates after the first and third application. Whereas spinosad significantly reduced *F. occidentalis* populations, it showed virtually no impact on populations of *F. tritici.* Mortality induced by insecticides apparently was compensated for by rapid recolonization by *F. tritici.* A comparison of the differences between the mulches supports this scenario. Populations in the black mulch treatments reached peaks from 11 May through 18 May 2001, which was during the period of insecticide applications, and then declined rapidly thereafter. In contrast, populations approached zero in the UV-reflective mulch treatments from the time of the first through second insecticide application. As with *F. occidentalis, F. tritici* populations were lower in the predator release treatments compared with the control for the first few sample days after releases (Table 3; Fig. 8).

*Frankliniella bispinosa* populations approached zero in all plots after 29 May 2001. Esfenvalerate provided substantial season-long suppression of *F. bispinosa* compared with the untreated control and with spinosad (Table 3; Fig. 9). Spinosad did reduce the abun-

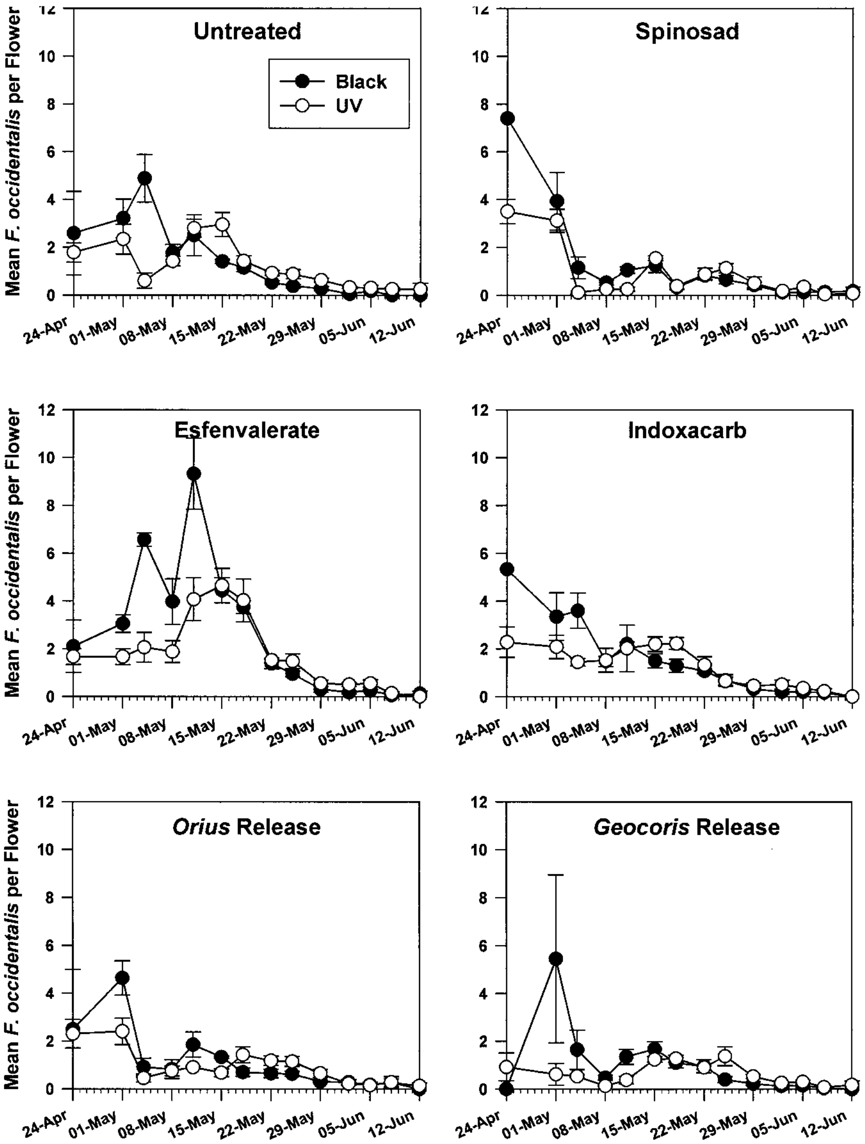


**Fig. 7.** Number (mean ± SEM) of adult thrips of *F. occidentalis* in flowers of pepper plants grown under different insect management and mulch treatments during the spring of 2001. Insecticide applications were made on 1, 8, and 15 May. Samples collected on those dates were collected before insecticide applications. Predators were released on 3 May. Means and their standard errors are based on untransformed data.

dance of *F. bispinosa* compared with the untreated control, but a postapplication difference was observed only on 11 May, the date of peak *F. bispinosa* abundance. Populations of *F. bispinosa* were lower in the predator release treatments compared with the control for the first few sample days after releases (Table 3; Fig. 9).

Thrips larvae showed complex responses to the insect management treatments. Over the season, there were significantly more larvae in the UV-reflective mulch compared with the black mulch (Table 1; Fig. 10). However, the pattern changed over time, with few larvae in UV-reflective mulch plots early in the season, and proportionately more later in the season compared with black mulch. Because responses changed with sample date and mulch type ($F = 2.28$; df = 45, 261; $P = 0.002$ for mulch by insecticide/predator release treatment by date interaction), we tested the effects of insect management treatments over time separately for each of the mulches. However, results were similar to tests with the mulches combined; therefore we report only the combined analyses. Spinosad suppressed larval thrips in both mulches throughout the season (Fig. 10). The pred-

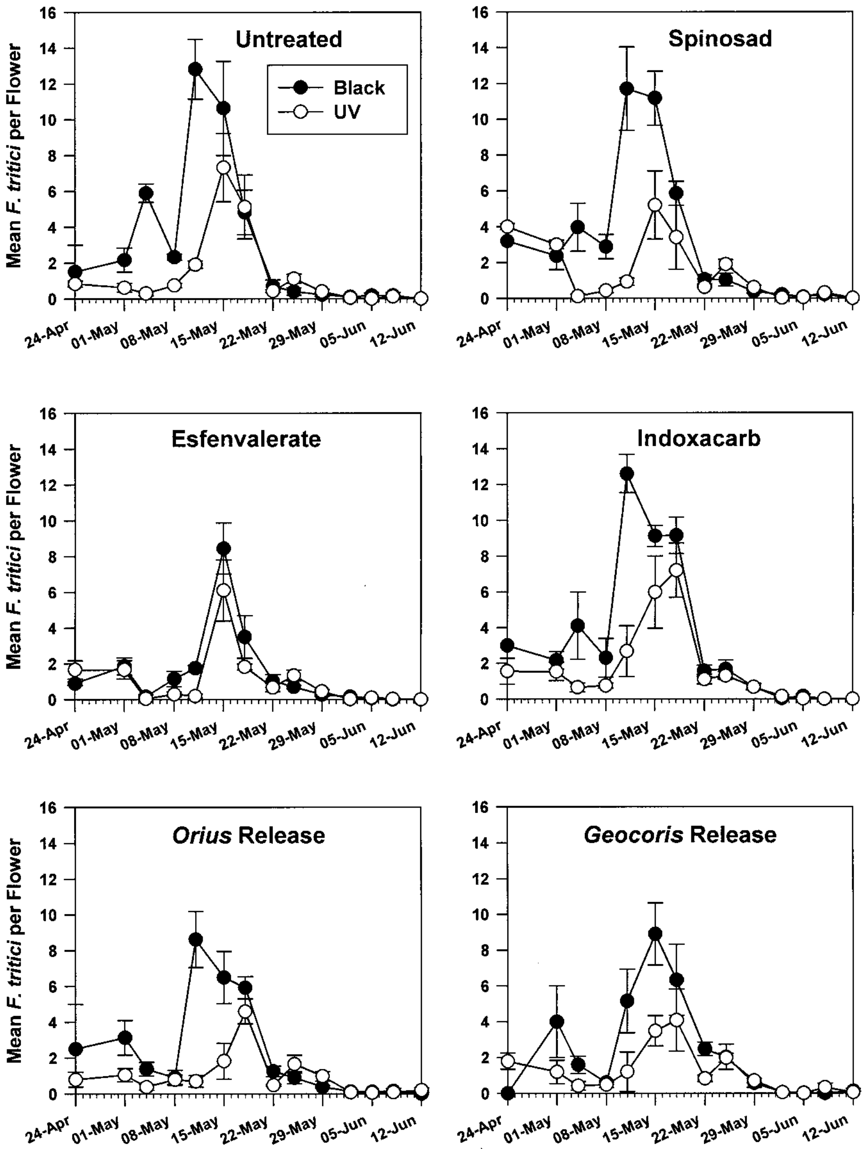


**Fig. 8.** Number (mean ± SEM) of adult thrips of *F. tritici* in flowers of pepper plants grown under different insect management and mulch treatments during the spring of 2001. Insecticide applications were made on 1, 8, and 15 May. Samples collected on those dates were collected before insecticide applications. Predators were released on 3 May. Means and their standard errors are based on untransformed data.

ators also kept larval thrips at low numbers; however, they did not provide control to the same extent as spinosad (Table 3; Fig. 10). Esfenvalerate did not suppress numbers of thrips larvae. Number of thrips larvae in this treatment were significantly higher than those in the untreated plots on the sample days following each of the applications (Table 3; Fig. 10), and numbers continued to increase following the first two applications. Indoxacarb did not appear to adversely affect thrips larvae, as there were significantly more in that treatment compared with the untreated plots (Table 3; Fig. 10).

Despite variation in the number of TSWV vector species across treatments, there was no significant difference in the incidence of tomato spotted wilt (mulches: $F = 1.00$; df = 1, 3; $P = 0.41$, treatments: $F = 0.97$; df = 5, 29; $P = 0.45$). Tomato spotted wilt pressure was extremely low in 2001, with a mean of 0.63 ± 0.25% across all treatments. Perhaps as a consequence of low disease incidence there were no significant differences in yield or fruit size between mulches ($P > 0.85$) or among insecticide or predator release treatments ($P > 0.44$). The mean yield was 16,538 ± 890 kg/ha across all treatments, and mean fruit size was 191.5 ± 4.1 g.

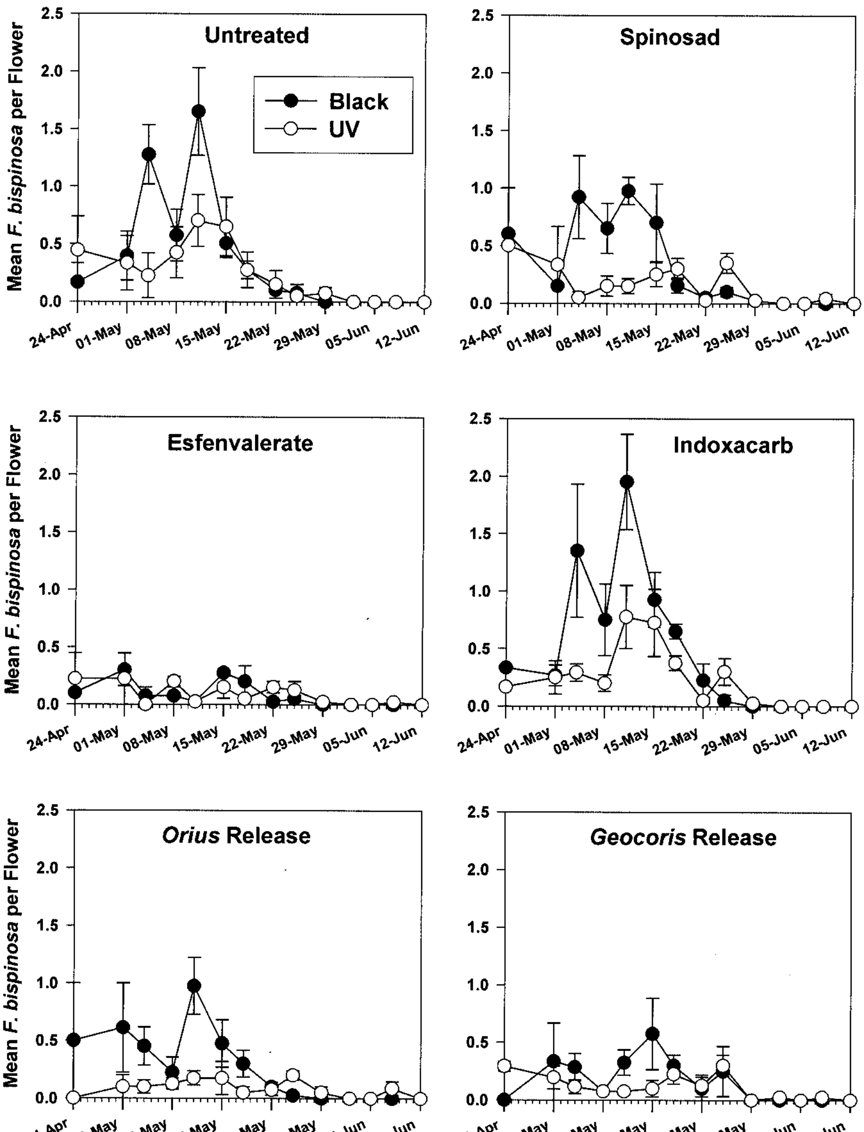


**Fig. 9.** Number (mean ± SEM) of adult thrips of *F. bispinosa* in flowers of pepper plants grown under different insect management and mulch treatments during the spring of 2001. Insecticide applications were made on 1, 8, and 15 May. Samples collected on those dates were collected before insecticide applications. Predators were released on 3 May. Means and their standard errors are based on untransformed data.

## Discussion

Our results indicate that alternative management tactics, such as the use of UV-reflective mulches, can be an important part of integrated pest management programs for thrips. However, the use of different mulches and other insect management tactics produce complex outcomes because of species-specific responses to these effects. Because of variation in how *Frankliniella* species respond to treatments, management tactics may be effective for one species without substantially reducing overall abundance of thrips. For example, spinosad effectively reduced *F. occidentalis* populations but not those of *F. bispinosa* or *F. tritici.* Therefore, accurate identification of species present in a field and an understanding of how and why species respond differently to various treatments are needed.

UV-reflective mulch suppressed early season abundance of adult thrips. Although much is known about the spectral responses of *Frankliniella* spp. (Walker 1974, Terry 1997), little is known of how plant type may mediate the effects of different types of mulches.

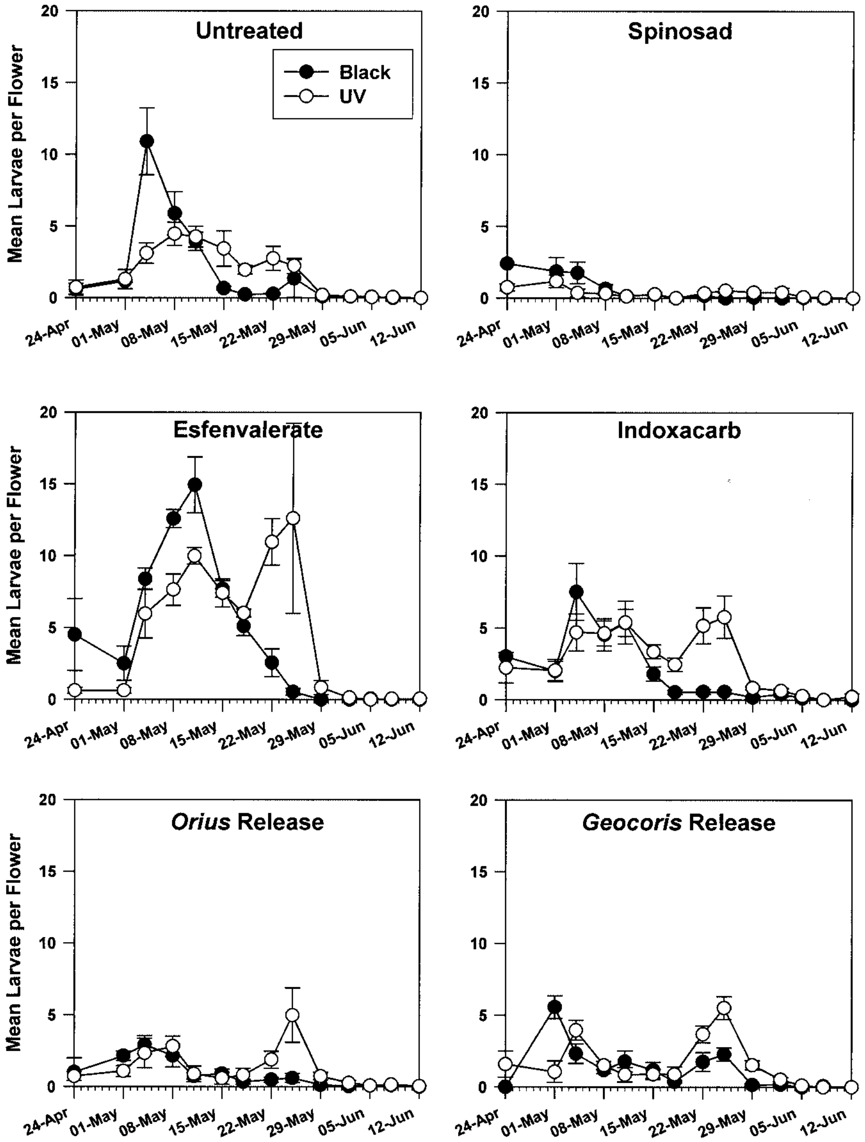


**Fig. 10.** Number (mean ± SEM) of larval thrips in flowers of pepper plants grown under different insect management and mulch treatments during the spring of 2001. Insecticide applications were made on 1, 8, and 15 May. Samples collected on those dates were collected before insecticide applications. Predators were released on 3 May. Means and their standard errors are based on untransformed data.

Tomatoes grown on UV-reflective mulch tend to have lower populations of adult *F. occidentalis* early in the season compared with those grown on black plastic mulch (Riley and Pappu 2000, Stavisky et al. 2002). Similar seasonal trends between UV-reflective and black mulch have been found for adults of other thrips species in tomatoes (Scott et al. 1989). Kring and Schuster (1992) argued that UV-reflective mulches should have longer lasting repellent effects in pepper than in tomato, because peppers are smaller and cover less of the mulch surface than larger tomato plants. However, pepper is a more suitable reproductive host than tomato for the species of *Frankliniella* that we examined. Therefore, the attractiveness of a highly suitable host may compensate for the UV repellency. In addition, the adult *Frankliniella* thrips collected in our samples were not necessarily all immigrants into plots. Some were likely progeny that had developed in those plots.

Two factors could account for overall higher larval populations in the UV-reflective mulch treatments. Although adults may have been deterred from UV-reflective mulches, some did alight in those plots. Once there, females oviposited, and progeny may have been relatively protected from natural enemies, such as *O. insidiosus* that seem deterred by UV reflectance. If so, UV-reflective mulch plots could be a source for secondary spread of TSWV. In fact, Greenough et al. (1990) found that UV-reflective mulches reduced numbers of thrips in pepper relative to black mulches, but these reductions in thrips numbers did not result in reduced incidence of tomato spotted wilt.

Although UV-reflective mulches can reduce thrips populations and incidence of tomato spotted wilt under certain conditions, they are not completely effective in controlling these problems. Therefore, additional management programs are needed. Other field studies have shown that *O. insidiosus* is capable of rapidly colonizing plants and suppressing *Frankliniella* spp. (Funderburk et al. 2000, Ramachandran et al. 2001). However, this valuable naturally occurring control may be disrupted if UV-reflective mulches retard colonization by natural enemies. Such a disruptive effect may have contributed to longer persistence of thrips populations in UV-reflective mulch plots. More research is needed on the effect of UV reflectance on movement of thrips and their natural enemies.

Many classes of insecticides, including several synthetic pyrethroids and organophosphates, are toxic to species of *Orius* (Ohtani et al. 1991, Van De Veire et al. 1996, Delbeke et al. 1997). Therefore use of such materials should be timed to not coincide with colonization of plants by *O. insidiosus* or other natural enemies, which usually occurs after bloom and coincides with peaks in thrips populations (Nagai 1990). In contrast to synthetic pyrethroids and organophosphates, our results indicate that spinosad is compatible with naturally occurring populations of *O. insidiosus.*

Although spinosad is highly toxic to *F. occidentalis, F. tritici,* and *F. bispinosa* in laboratory bioassays (Eger et al. 1998), our field study showed it to have significant effects only on *F. occidentalis* and thrips larvae. Ramachandran et al. (2001) hypothesized that this anomaly is a function of the relative mobility of the different species. They found that *F. tritici* and *F. bispinosa* were able to colonize plants more rapidly than *F. occidentalis.* In fact, *F. tritici* and *F. bispinosa* are more active than *F. occidentalis* (Hansen 2000, S.R.R., unpublished data). Therefore, populations of these more active species would be expected to reinfest plots by immigration relatively quickly following insecticide applications. Rapid reinfestation may have been delayed in plots treated with esfenvalerate and acephate because of longer residual activities compared with spinosad.

Our results suggest that *O. insidiosus,* and possibly *G. punctipes,* remained in release plots long enough to reproduce successfully. Larger plot size may reduce the impact of dispersal and lead to a greater effect on thrips populations. Naturally occurring populations of *O. insidiosus,* as well as other natural enemies, probably contributed to the final population collapse of thrips in our study. The ability of *O. insidiosus* to control all of these *Frankliniella* species successfully is something none of the insecticides that we tested were capable of doing. Therefore, tactics that promote early season populations of natural enemies, either through conservation, environmental enhancements, or augmentative releases would be beneficial in suppressing peak populations of thrips and reducing insecticide use. *G. punctipes* may be an effective predator of thrips (Figs. 7 −10), but the circumstantial evidence that it interferes with *O. insidiosus* (Fig. 6) indicates that more information is needed on the extent to which *G. punctipes* acts as an intraguild predator of smaller Heteroptera.

In conclusion, we found that UV-reflective mulches can be beneficial in pepper production. Although in the two years of our study the incidence of tomato spotted wilt was relatively low, UV-reflective mulches may provide greater reductions in the incidence of tomato spotted wilt compared with other types of mulches when disease pressure is higher (Stavisky et al. 2002). If standard black mulches are used, early season populations of *F. occidentalis* may be suppressed best by use of spinosad early in the growing season. Few applications would be needed because indigenous natural enemies, such as *O. insidiosus* and *G. punctipes,* can colonize pepper readily to keep thrips populations low.

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